STRESS ANALYSIS OF NAIL-PLATE DEVICES USED IN THE FIXATION OF FRACTURES ABOUT THE HIP

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DEDICATION:

To the Dean and faculty

of the Yale University School of Medicine,

whose patient teaching, guidance and friendship

enabled me to realize my ambitions in the study of medicine.

And to my family,

whose devotion and loyalty inspired me.

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PURPOSE:

To study the points of stress concentration in some standard and experimental nail-plate combinations used in the fixation of fractures about the hip.

DESCRIPTION & METHOD:

PART 1

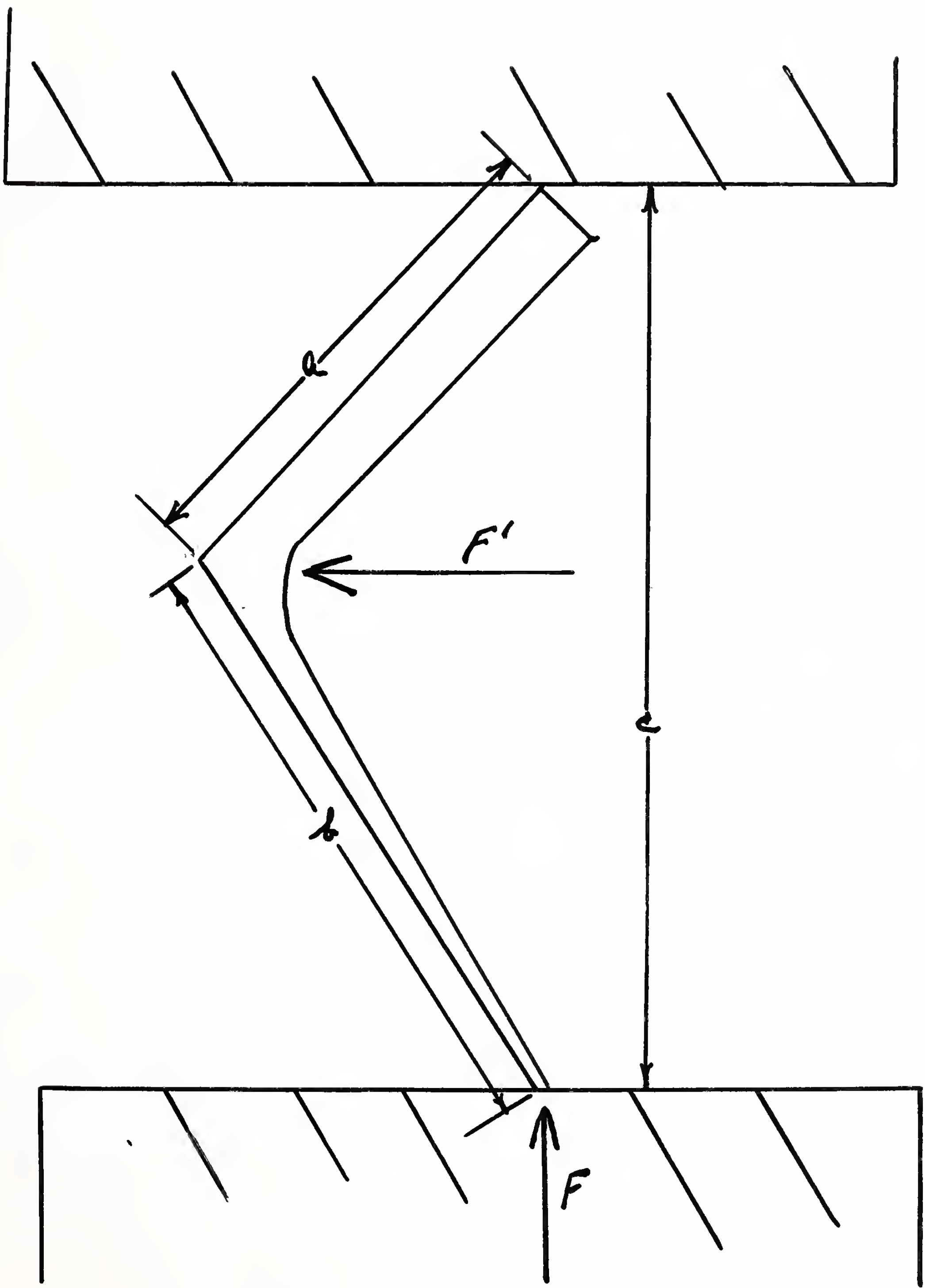
Evaluation of existing nail-plate combinations.

Stresscoat was applied to the materials to be tested according to the technique outlined by the Magnaflux Corp. (New York; Chicago). Stresscoat is a brittle lacquer developed by the Magnaflux Corp. for use by mechanical and aeuronotical engineers in analysis and prevention of fatigue failures in metals. This lacquer is calibrated, taking into consideration the temperature and humidity of the testing area; so that the results obtained are quantitative as well as qualitative. Six (6) standard nail-plate combinations were sprayed with Stresscoat, dried sufficiently, and tested in a Carver Laboratory Press. The nails were placed in the press and loaded as noted in figure 1. The loads were increased in increments of 20-30 lbs., with 30 seconds of No-Load after each successive load to correct for "creep" of the lacquer on

the metal.

The first evidence of stress concentration is marked by a crack in the Stresscoat. The cracks in the lacquer indicate only points of tension forces, it being assumed that the fatique failure will occur at the point or points of greatest stress (tension) concentration. As more force is added, there appear other patterns (indicated by cracks in the lacquer) at other points on the appliance, as well as an increase in the patterns already produced. With each load increment, the new patterns are outlined on the appliance with a marking pencil. Cracks are best detected in a darkened room using a tangential beam of light to detect the earliest changes produced. The location of the earliest cracks obtained (at minimum load) indicate the weakest part of each specimen, and hence the part or point of the appliance which would fail in actual service.

FIGURE 1



In Figure 1, knowing the distances a, b, c, and the angle at the neck, one could compute the horizontal force (F') acting on the neck from any vertical load F (scale reading) by use of a factor for each individual nail (determined by its dimensions). Thus we may calculate the effective force (F') exerted on the neck from any scale load reading (F). The different values for F' are therefore directly comparable, without reference to the dimensions of the respective nail-plate combinations.

F' can also be calculated graphically using vector diagrams done to scale according to the exact dimensions of the particular nail. This method was considered satisfactory for complying with the standards of technical accuracy achieved in the rest of this investigation.

Testing each nail produced particular and characteristic patterns of cracks in the Stresscoat lacquer at the various loads. This data was recorded in detail for each individual nail, but all this data is not presented in its entirety here. There has been more of an effort made to compare the behavior of the various nails, rather than to describe completely any one particular nail under all the testing conditions.

The following nail-plate combinations were tested according to the above description:

1. Vitallium Jewet Nail (Austenal)

2. Neufeld Nail Smo stainless (Richards)

3. Welded Jewet Nail-Plate Combination, Smo stainless (Zimmer)

4. One Piece Drop Forge Jewet, Smo stainless (Zimmer)

5. Thornton Side Plate with modified Smith-Peterson Nail, Smo stainless (Zimmer)

6. Austin-Moore Blade Plate, Smo stainless (Zimmer)

Lacquer sensitivity for the experiments was .001.

Part 1

Results:

a. Scale load readings and effective neck loads at which the first evidence of stress concentration appeared in Stress-coat, and location of the earliest cracks.

(Holes are numbered so hole #1 is closest to the neck.)

TABLE 1

Nail-plate Combination	Scale load Reading	Effective Neck load	Location of Earliest cracks
1. Vitallium	95	22.4	Plate sides, then holes #2 and #3
2. Neufeld	20	4.9	Neck angle, then hole #1
3. Zimmer Welded Smo Stainless	30	7.2	Hollow of neck, then hole #1
4. Drop Forge Zimmer Smo Stainless	80	17.0	Hole #1, then hole #2
5. Thorton Side Plate with Smith-Peterson Nail	60	14.1	Neck (bend of plate)
6. Austin-Moore Blade Plate	40	9.0	At neck (starting at sides of base of guide hole)

Part 1

Results (continued)

b. Scale load readings and effective neck loads at which the appliance assumed a permanent bend, and location of the point of permanent bend.

TABLE 2

Neck-plate Combination	Scale load Reading	Effective Neck load	Location of Earliest cracks
1. Vitallium	230	52	At hole #3 (1/2" from neck)
2. Neufeld	120	29.4	At neck angle
3. Welded Zimmer Smo stainless	105	35.8	At neck (top of shaft)
4. Drop Forge Zimmer Smo stainless	170	36.0	At hole #1 (1 and 1/2" from neck)
5. Thornton Side Plate with Smith-Peterson Nail	190	44.5	At neck (top of shaft)
6. Austin-Moore Blade Plate	140	31.4	At neck and down length of shaft to hole #1

Part 1

Results (continued)

c. Scale load readings and effective neck loads at which the first evidence of stress concentration was noted at the screw holes, and location of screw hole by number.

TABLE 3

Nail-plate Combination	Scale load Reading	Effective Neck load	Screw hole number
1. Vitallium	120	27.2	#2, #3
2. Neufeld	50	12.2	#1
3. Welded Zimmer Smo stainless	30	7.2	#1
4. Drop Forge Zimmer Smo stainless	80	17.0	#1
5. Thornton Side Plate with Smith-Peterson Nail	80	18.7	#1
6. Austin-Moore Blade Plate	60	13.4	#1

Part 1

Results (continued)

d. Scale load readings and effective neck loads at which the first evidence of stress concentration was noted at the upper fins of the tri-flange.

TABLE 4

Nail-plate Combination	Scale load Reading	Effective Neck load	Location on tri-flange as distance from neck
1. Vitallium	140	31.6	1/2 cm.
2. Neufeld	75	18.8	Continuous from neck up to 1/2 cm on flange.
3. Welded Zimmer Smo stainless	50	11.9	The base of flange.
4. Drop Forge Zimmer Smo stainless	120	25.4	1 cm. from neck.
5. Thornton Side Plate with Smith-Peterson Nail	100	23.4	1 cm. from neck, extending for 1" distally.
6. Austin-Moore Blade Plate	No patterns *		

* There is no tri-flange as such on the Austin-Moore Blade Plate. The blade, which inserts into the head of the femur, has a concave surface on its inferior aspect. The sides of this blade are, therefore, under compression forces (rather than tension which the Stresscoat lacquer measures) when the loads are applied; hence, one would not look for evidence of tension forces on the blade edges. The reinforced superior surface of the blade, on the other hand, should be under tension when load is applied. However, the weakness produced by the bend at the neck, so weakens this nail that it assumes deformity at the neck before the tension at the superior surface is severe enough to produce cracks in the Stresscoat.

Part 1

Discussion

Comparing Tables 1 and 2, it is noted that failure occurred at the point where Stresscoat gave the earliest evidence of stress concentration.

By inspection of charts a, c, and d, one notes the difference in load values at which stress is concentrated at the screw hole, the neck, and the tri-flange for the individual nail-plate combinations. A nail-plate combination is, therefore, like a chain, as strong as its weakest link or most stressed portion. The weaker any given area, the earlier will it concentrate stress, as compared to other areas where stress concentration is demonstrated only at higher load readings. The ideal and ultimate purpose in designing a nail-plate combination, with due regard for stress concentrating factors, would be to design an appliance which, when it does show stress concentration, does so throughout its entire structure - no one area concentrating stress earlier or at lower load than any other.

Part 2

EXPERIMENTAL NAIL-PLATE COMBINATIONS

A series of three (3) experimental nail-plate combinations was devised by taking wax castings of the Vitallium Jewet nail and filling in the following areas of the respective models, being guided by the information obtained in Part 1.

Experimental Nail #1

The side plate was filled in from the neck down to the lower tip, producing a smooth surface along the entire side plate. The tri-flange was not altered.

Experimental Nail #2

The top of the tri-flange was filled in so that the superior part of the nail presented a continuous smooth surface. The side plate was not altered.

Experimental Nail #3

The changes made in #1 (on side plate) and in #2 (on tri-flange) were both incorporated in the same nail.

The wax casts were finished and buffed, with care being taken to produce uniform, gradual and smooth contours in place of stress concentrating sharp edges.

<u>Experimental Nail #3</u> (continued)

Nail holes were drilled in all three experimental wax models as on the original Vitallium Jewet. The Austenal Laboratories then cast the wax models in Vitallium according to the lost wax process. The three experimental nails were then sprayed with Stresscoat and tested in the Carver press, using the same techniques as outlined in Part 1.

Part 2

Results:

a. Scale load readings and effective neck loads at which the first evidence of stress concentration appeared in Stresscoat, and the location of the earliest cracks.

(Holes are numbered so hole #1 is closest to the neck.)

TABLE 5

Nail-plate Combination	Scale load Reading	Effective Neck load	Location of Earliest cracks
1. #1 Experimental Model	120	29.0	At neck (top of shaft)
2. #2 Experimental Model	80	19.9	Hole #1, #2, #3, #4
3. #3 Experimental Model	100	24.8	Hole #4

Part 2

Results: (continued)

b. Scale load readings and effective neck loads at thich the appliance assumed a permanent bend, and location of the point of permanent bend.

TABLE 6

Nail-plate Combination	Scale load Reading	Effective Neck load	Location of Permanent bend
1. #1 Experimental Model	280	69.5	Tri-flange 1" from neck, and hole #5
2. #2 Experimental Model	180	44.5	Hole #3 to hole #5
3. #3 Experimental Model	260	64.5	Hole #5

Part 2

Results: (continued)

c. Scale load readings and effective neck loads at which the first evidence of stress concentration was noted at the screw hole, and location of the screw hole(s) by number.

TABLE 7

Nail-plate Combination	Scale load Reading	Effective Neck load	Location of Screw hole
1. #1 Experimental Model	140	34.8	#1, #3, #4; #5
2. #2 Experimental Model	80	19.9	#1, #2, #3; #4
3. #3 Experimental Model	100	24.8	#5

Part 2

Results: (continued)

d. Scale load readings and effective neck loads at which the first evidence of stress concentration was noted at the upper fins of the tri-flange.

TABLE 8

Nail-plate Combination	Scale load Reading	Effective Neck load	Location on tri-flange as distance from neck
1. #1 Experimental Model	140	34.8	Base to 1/2" on tri-flange
2. #2 Experimental Model	..........no patterns...............		
3. #3 Experimental Model	200	49.8	2" from neck

Parts 1 and 2

DISCUSSION

Though it is true that the appliances tested were designed primarily for the purpose of immobilization and alignment of the fractured fragments of the proximal femur, it is nevertheless important to have some margin of safety to protect against the possible and often probable uncalculated mis-step of the fracture patient. When one realizes that the force exerted on the hip joint is 2 1/2 times the body weight when the body weight is balanced on one foot, it becomes quite obvious, in view of the data obtained, that the present standard nail-plate combinations would fail in the event of a possible mis-step, the improper use of crutches, or the patient who, because of minimal pain, indulges in some partial weight bearing contrary to the advice of his physician.

Parts 1 and 2

CONCLUSIONS

1. None of the nails tested approaches the maximum obtainable strength.
2. Stress concentration invariably occurred at the screw hole.
3. Stress concentration invariably occurred at the junction of the nail and plate.
4. Stress was also concentrated along the upper fins of the tri-flange nail.
5. The appliance yields by permanent bend at the point where Stresscoat shows the greatest stress concentration.
6. The modifications made in the three experimental nails clearly demonstrated their increased strength and reduced stress concentration under equivalent testing conditions.

Date Due
